ACTA BIOLOGICA SIBIRICA
A journal on the biodiversity of Siberia and the adjacent lands

Acta Biologica Sibirica 7: 63–76 (2021)
doi: 10.3897/abs.7.e62111
https://abs.pensoft.net

RESEARCH ARTICLE

Distribution of *Acer negundo* L. in Altai Krai (Russia, Southern Siberia) and its coenotic role in pine forests

Marina M. Silantyeva[1], Natalia V. Ovcharova[1], Tatiana A. Terekhina[1], Anastasia O. Nesterova[2], Natalia V. Elesova[1], Tatyana V. Kornievskaya[1], Natalia Yu. Speranskaya[1]

1 *Altai State University, 61 Lenina prospect, 656049, Barnaul, Russia*
2 *Ministry of Natural Resources and Environment of Altai Krai, 230 Chkalova st., 656049, Barnaul, Russia*

Corresponding author: Natalia V. Ovcharova (ovcharova_n_w@mail.ru)

Academic editor: A. Matsyura | Received 16 December 2020 | Accepted 2 April 2021 | Published 19 April 2021

http://zoobank.org/102F6F77-1F01-4D59-BBCD-CDDB41B7F819

Citation: Silantyeva MM, Ovcharova NV, Terekhina TA, Nesterova AO, Elesova NV, Kornievskaya TV, Speranskaya NYu (2021) Distribution of *Acer negundo* L. in Altai Krai (Russia, Southern Siberia) and its coenotic role in pine forests. Acta Biologica Sibirica 7: 63–76 https://doi.org/10.3897/abs.7.e62111

Abstract

The article provides data on the distribution of the invasive boxelder maple in the Altai Krai. The article specifically considers its coenotic role in pine forests by the example of the Barnaul ribbon pine forest. A GIS project was developed to assess the distribution of boxelder maple in Altai krai. Mapping was based on the species location data obtained from the herbarium material (more than 500 sheets of the herbarium) deposited to the Altai State University (ALTB), the N.I. Vavilov All-Russian Plant Research Institute (WIR) and the V.L. Komarov Botanical Institute of the Russian Academy of Sciences (LE). To map the boxelder maple distribution, an analysis of the forest stand maps of the Barnaul ribbon pine forest was also carried out (2010, 2018). For each maple location, the stratum, the stratum area, and the stand formula are taken into account. Over the ten-year observation period, the area of maple and mixed forests with the participation of *Acer negundo* has increased almost 6 times here. Monodominant maple forests and mixed forests with the participation of boxelder maple as well as with other invasive species are formed. This leads to a considerable anthropogenic transformation of pine forests and a decrease in their environment-forming, social-economic and ecological significance. The study reveals that generative plants were not found in every coenopopulation. If the plants reached the reproductive stage, then, on the whole, males prevailed fivefold in the coenopopulation. Most of the studied coenopopulations consisted of pre-generative individuals, with the exception of occasional young generative ones. Most of the trees in the studied populations reached the age of

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10–15 years. For forest communities of the Barnaul forestry, two age periods of the ontogenetic state have been established – pre-generative and generative, which indicates a relatively early age of the phytoinvasion and its active stage.

Keywords
Acer negundo L., distribution, biological invasion, forest typologies, ontogenetic structure of populations

Introduction

Researchers consider the problem of phytoinvasions as one of the reasons for the extinction of biological species and the loss of floristic diversity. At the present stage of the transformation of natural ecosystems by mankind, it has become global-scale.

The disturbance of successional processes by alien species is an understudied ecological consequence of phytoinvasions. The consequences of the successional processes' disruption can be a delay at certain stages, blocking of successional changes, an unpredictable pathway, a decrease in the variability of the ecosystem states – "successional diversity". These changes, in turn, are reflected in biodiversity (a decrease in successional variability leads to the loss of habitats and, accordingly, biodiversity). The formation of new communities and ecosystems, including those with unpredictable characteristics is probable. Blocking successions by alien species negatively affects the rate of successional processes, which reduces the resistance of natural and natural-anthropogenic ecosystems to external influences.

The most aggressive invasive species, ranking first in Russia in terms of ecological and economic consequences, is *Acer negundo* L. – boxelder maple or ash-leaved maple. This naturalized introduced species has penetrated into many phytocenoses. Forests in Europe were particularly affected, as evidenced by the extensive bibliography (Richardson at al. 2000; Yemelyanov and Frolova 2011; Richardson and Pyšek 2012; Kostina at al. 2015; Marozas 2015; Gusev 2016a; Gusev at al. 2016b; Gusev, Shpilevskaya and Veselkin 2016c; Gusev, Shpilevskaya and Veselkin 2017). The introduction of the boxelder maple changes the natural course of the secondary succession. However, the mechanism of the introduced species penetration into forest communities, as well as the consequences for successional changes, are not fully understood. The study of the maple influence on the forests of Siberia, where maple is also the number one aggressor, has not been carried out before.

In recent decades, there has been an avalanche-like increasing tendency for maple penetration into the phytocenoses of the unique world-famous ribbon pine forests of Altai Krai (Russia, Southern Siberia). These are the world largest pine forests in the form of bands with sod-podzolic soils on ancient alluvial sands found along the ancient runoff hollows that cut the Altai Krai with seven parallel lines running from the north-east to the south-west. The longest is the strip of the Barnaul pine forest, which stretches for 550 km from the Ob River in the vicinity of Barnaul to the

Irtysh River. Three pine forest bands within the region, Kulunda, Barnaul and Kasmala (Figs 1, 2, 3, 4), cross two natural zones - forest-steppe and steppe. The whole of Aleusskiy band (Fig. 5) is located within the left-bank forest-steppe. Experts still argue about the age and the origin of the forests and the growing conditions.

Ribbon forests with scattered chains of lakes and bogs have a great influence not only on the formation of microclimate in the forest cenoses, but also contribute to an increase in convection processes, the cloud formation and the intensification of thunderstorm activity. As a result, there is 40–50 mm more precipitation in and around the pine forests than on the dividing ridges. They also weaken the wind force, increase the relative humidity, contribute to the accumulation of snow cover, significantly improve the water regime of the soil, and have a mildening effect on the microclimate of the adjacent areas. In summer, the pine forest is a natural obstacle to dry Asian winds, dust and sand storms, protecting crops from wind erosion.

Despite the status of the protective forests, in the past decade, the volume of felling has increased 5 times compared to the previous decade. The situation is aggravated by the fact that under the guise of improvement cutting, the tallest healthy trees suitable for the production of industrial wood are cut down instead of sick, damaged, oppressed, and stunted ones. In addition, in 2008, disregarding scientific substantiation, the age of pine felling in the ribbon pine forests was decreased from 121 to 101, which led to an increase in the volume of the main forest-forming species logging.

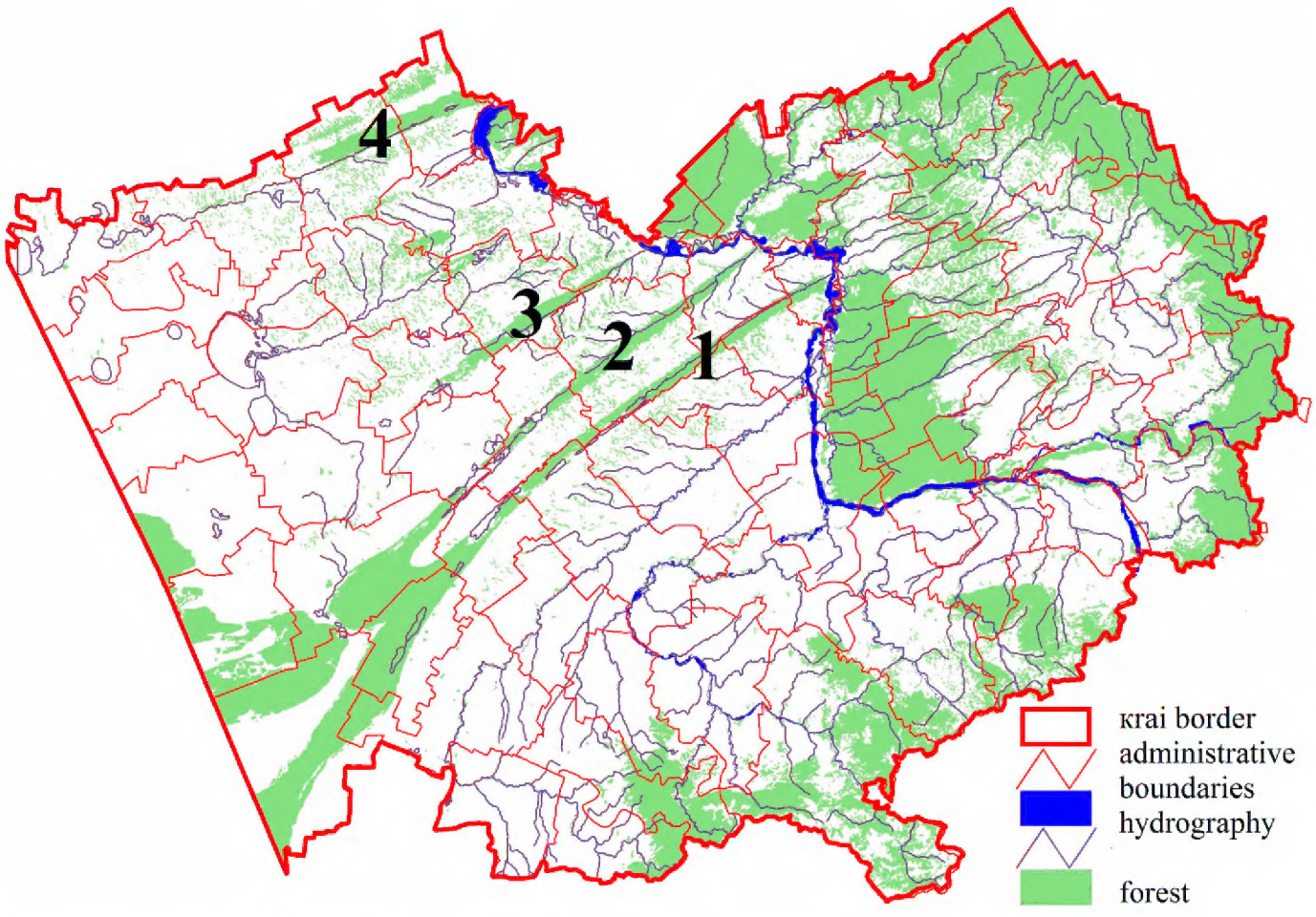

Figure 1. Map-scheme of the location of pine forests in Altai Krai. Numerals indicate: **1** - Barnaulskaya, **2** - Kasmalinskaya, **3** - Kulundinskaya, **4** - Aleusskaya pine forests.

Figure 2. Monodominant community with *A. negundo* in Barnaul ribbon forest.

Figure 3. Kasmalin pine forest (*A. negundo* more than 25 years old).

Figure 4. Kulunda pine forest belt.

Figure 5. Aleusian pine forest with the participation of *A. negundo* in the shrub layer.

Due to overcutting and overexploitation of the ribbon pine forests in recent years, the ash-leaved maple, which is one of the biologically aggressive (invasive) species, has penetrated into the forest communities. Its introduction into the affected natural communities causes the light and mineral regime changes, and plant species common for the original community disappear. In some cases, dead-cover areas with almost complete absence of grass stand are formed (Silanteva and Kirina 2016).

One of our goals was to analyze the distribution of the boxelder maple in the Altai Krai and to pre-assess its coenotic role in the pine forests.

Material and methods

A GIS project was developed to assess the distribution of boxelder maple in Altai krai. Mapping was based on the species location data obtained from the herbarium material deposited in the Altai State University (ALTB), the N.I. Vavilov All-Russian Plant Research Institute (WIR), and the V.L. Komarov Botanical Institute of the Russian Academy of Sciences (LE). We studied and photographed more than 500 sheets of the herbarium. The Microsoft Excel database was compiled. It consists of tables reflecting the geographical location, coordinates, the phytocenosis, the date of collection, collectors. In addition to creating databases, track studies were carried out.

During the expeditions, the GPS coordinates of the boxelder maple locations were recorded, at some points herbarium samples were collected. The resulting tables were uploaded onto the created substrates in the form of point layers. Each layer reflects the information on the coordinates obtained from different sources and contains point objects of different colors: pink for literature data, yellow for herbarium material, red for coordinates recorded during the expedition.

To map the distribution of the boxelder maple, an analysis of the forest stand maps of the Barnaul ribbon pine forest was also carried out (2010, 2018). For each maple location, the stratum, the stratum area and the stand formula are taken into account.

Results

The natural range of *Acer negundo* L. covers North America (from the Rocky Mountains to the Atlantic coast and from Canada to Florida) (Bakulin 1982). The continuous range extends from New Jersey and New York to the very south of Ontario, to central Michigan, northern Minnesota, central Manitoba, central Saskatchewan and southern Alberta, central Montana, and eastern Wyoming, Utah, and California; in the south, the border runs through the south of Texas and the central Florida. Local populations are also found in New Hampshire, Vermont, Massachusetts, Connecticut, Idaho, and Nevada (Vinogradova at al. 2010; Mędrzycki 2011).

The secondary range of *A. negundo* in Europe is associated with the decorative collections development with the North American plants in the 17th century (Vinogradova and Kuklina 2012). In Russia, it has been known since the second half of the 18th century, when the experiments on the introduction of the maple from seeds in the botanical gardens of St. Petersburg and Moscow began. The first attempts to introduce the plant were not successful. The seedlings died, as they were grown from the seeds taken from the plants naturally dwelling in the southern part of North America. It was only in the 19th century that the boxelder was finally grown from the seeds obtained in Canada (Bogolyubov 2013).

The maple penetrated into the Altai Krai by two routes. The first is associated with the creation of protective forest ranges along with the establishment of specialized agroforestry nurseries in the steppe part of the region back in the 20s of the last century. The greatest amount of work in creating windbreaks was carried out in the 1960s. The second route of introduction is associated with the use of the maple as a decorative plant. In Siberia, in the 1950s, *A. negundo* participated in almost every softscape. In the process of naturalization, the maple has become a winter- and drought-resistant species, which forms a lot of seeds easily dispersed for long distances. It was precisely its ecological plasticity that, in general, determined the success of the species as one of the basic (since 1927) for the creation of windbreaks in Altai Krai, especially in the dry steppe zone of Kulunda Steppe, where other woody deciduous species did not survive. Since the 1970s, the maple has become increasingly common in the forest communities (Silanteva and Kirina 2016).

The analysis of the box elder distribution on the territory of the region revealed local biological and morphological features of the maple. Thus, on the territory of the Krai, *A. negundo* is mostly a tree up to 20 m tall with a wide branchy crown, and a trunk diameter of 5 to 70 cm. The branching pattern of the maple depends on the habitat conditions. In places with moderate moisture, it has the shape of an upright tree with one trunk. If shaded, the tree becomes multitrunked, the trunks bend strongly. The boxelder maple is susceptible to snow breakage and recurrent freezing of annual shoots, hence the trees take the form of a bush and produce abundant self-seeding.

In local conditions, the boxelder maple grows rapidly and reproduces by seeds and shoots, which grow up to 2–2.5 m in height during the growing season. The data on the onset of seed reproduction in *A. negundo* previously obtained by researchers (Mędrzycki 2011; Veselkin at al. 2018) is confirmed. In open, unshaded areas, individuals form mature seeds at the age of 5 and up, while in shaded conditions, when the plants develop under the forest canopy, seed regeneration starts when the trees reach 15 years of age. On the territory of the krai, the boxelder maple is resistant to medium salinity, shade, and gas.

As it was mentioned before, *A. negundo*, being able to reproduce not only by seeds, but also by shoots, has widely spread throughout the territory of the Krai (Fig. 6).

The ash-leaved maple is not common in herbarium collections. Collectors tend to skip it as a background species. This is evidenced by the registered coordinates of

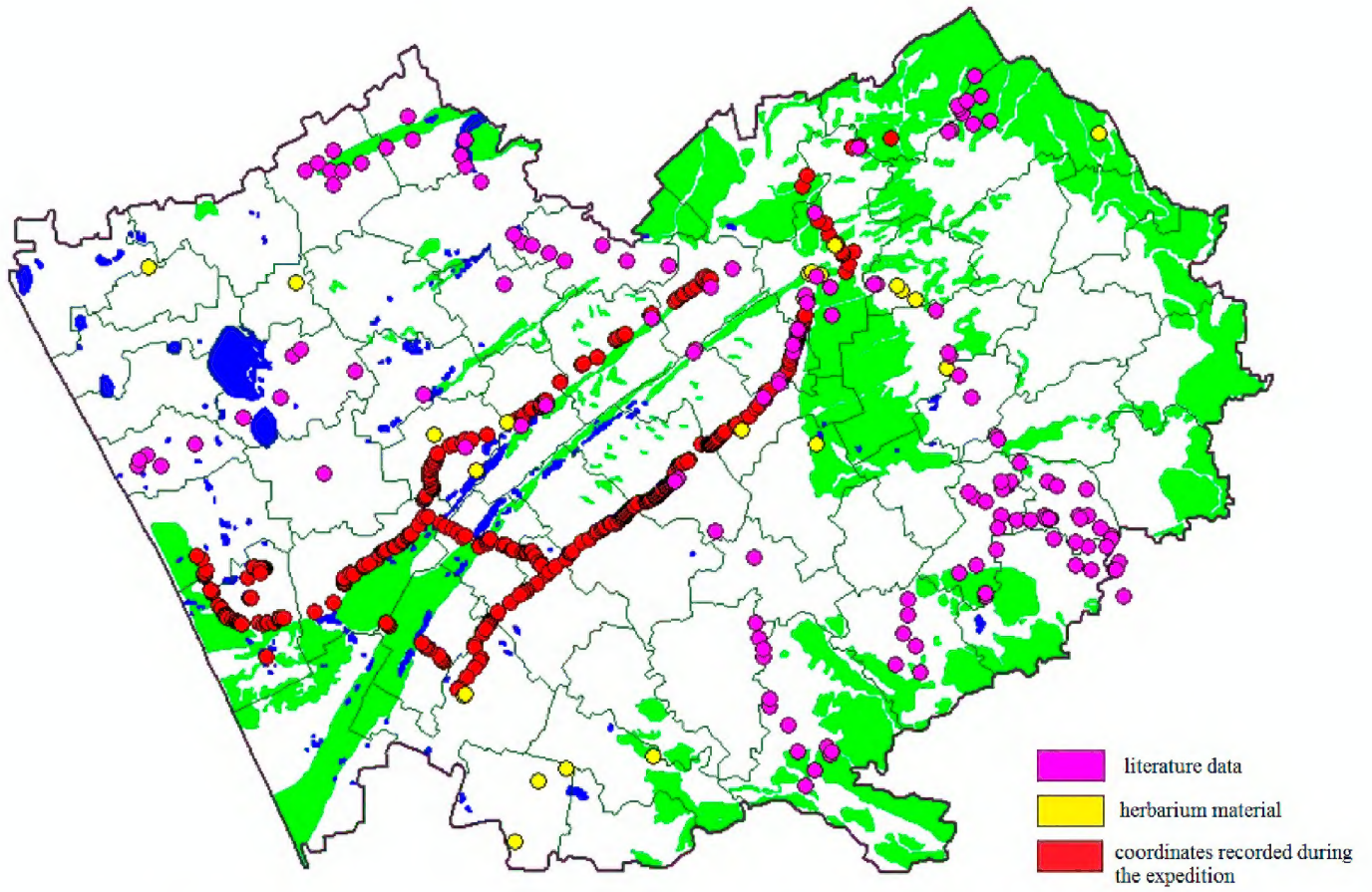

Figure 6. Distribution of *A. negundo* in the Altai Krai (Russia, Southern Siberia).

the maple locations during expeditions. In many places, the maple is almost ubiquitous, and with point mapping, the distribution area can be almost continuous. The species is most widely represented in the steppe and forest-steppe zones, is less common in the forest belt, and is not recorded in the highlands.

Discussion

The coenotic role in the forests. As it was mentioned before, the ribbon forests are of great environmental, social-economic and ecological significance for Altai Krai. They serve as the main source of timber for the residents of the steppe zone. Traditionally, they are a place for recreation, picking up berries and mushrooms. The role of the ribbon pine forests in the preservation of populations of vulnerable and rare plant, fungus, and animal species is significant.

The Barnaul ribbon forest is located within 7 forest districts. The analysis of the forest inventories in the Barnaul pine forest band in 2010 and 2018 resulted in the record of 221 *Acer negundo* locations. During the expedition in 2019, we found 115 additional points of the maple location in the Barnaul ribbon pine forest and performed 93 geobotanical descriptions of the communities formed by the maple and mixed communities with its significant participation. The analysis results are presented in Table 1.

The boxelder maple grows throughout the Barnaul ribbon forest, but with various frequency and abundance in its different parts. It is registered in all forest dis-

Table 1. Dynamics of *A. negundo* distribution in the Barnaul ribbon forest according to the analysis of the forest inventory results in 2010 and 2018.

№	Forestry, forest district	Number of strata/ compartments where *A. negundo* was recorded		Area occupied by *A. negundo*, ha		Other alien tree species/ monodominant and mixed communities with *A. negundo*
		2010	2018	2010	2018	
1	Barnaul Forestry					
1.1	Barnaul forest district	40 /25	46/30	32.0	34.2	*Malus baccata* (L.) Borkh./ Maple forests and mixed forests in 15 strata – 8.3 ha
1.2	Vlasikha forest district	8/5	8/6	9.0	11.4	*Fraxinus pennsylvanica* Marshall, *Malus baccata* (L.) Borkh./ mixed forests in 6 strata – 8.1 ha
1.3	Zimari forest district	8/6	11/8	13.1	14.9	*Malus baccata* (L.) Borkh., *Tilia cordata* Mill., *Salix fragilis* L. / In 2010, monodominant maple forest in 1 stratum – 0.8 ha
1.4	Cheremnoye forest district	-	8/6	-	24.7	Willow, willow-birch forests with the participation of *Acer negundo* L., *Betula pubescens* Ehrh., *Padus avium* Mill.
2	Pavlovsk forestry					
2.1	Zimino forest district	-	11/9	-	31.4	Monodominant maple forests in 5 strata of 4 compartments – 8.8 ha
3	Rebrikha forestry					
3.1	Voronikha forest district	-	1/1	-	0.8	Monodominant maple forests in 1 stratum – 0.8 ha
4	Novichikha forestry					
4.1	Krestyanka forest district	-	15/8	-	39.1	Monodominant maple forests and mixed pine-maple forests with the participation of *Pinus sylvestris* L., *Betula pubescens* Ehrh. In 3 strata – 9.6 ha
4.2	Polomoshnoye forest district	-	1/1	-	8.8	Monodominant maple forests
4.3	Novichikha forest district	-	18/5	-	74.4	Monodominant maple forests in 5 strata – 17.9 ha, mixed willow-maple and maple-birch forests with the participation of *Pinus sylvestris* L., *Salix fragilis* L., *Betula pubescens* Ehrh. in 13 strata

№	Forestry, forest district	Number of strata/ compartments where *A. negundo* was recorded		Area occupied by *A. negundo*, ha		Other alien tree species/ monodominant and mixed communities with *A. negundo*
		2010	2018	2010	2018	
4.4	Tokarevo forest district	–	4/3	–	3.6	Monodominant maple forests in 1 stratum – 0.7 ha, maple-willow communities in 1 compartment – 1.0 ha, pine-maple forest in 1 compartment – 1.9 ha.
4.5	Melnikovo forest district	–	3/3	–	6.9	Monodominant maple forests in 1 compartment – 1.2 ha, maple-poplar forest in 1 compartment – 3.3 ha.
5	Lebyazhye forestry					
5.1	Srosty forest district	–	9/3	–	12.9	Mixed pine-maple forests with the participation of *Pinus sylvestris* L., *Betula pubescens* Ehrh. in 3 strata – 3.4 ha
5.2	Novosovetskiy forest district	–	11/4	–	7.5	Monodominant maple forests in 2 compartments – 1.9 ha, mixed maple-aspen and maple-pine forests – 5.6 ha.
5.3	Kurortnoye forest district	–	18/6	–	29.6	*Malus baccata* (L.) Borkh. / Monodominant maple forests and maple forests with the participation of pine in 8 strata – 13.2 ha, maple-pine and maple-pine-birch forests in 8 strata – 16.4 ha.
6	Rakity forestry					
6.1	Shubinka forest district	–	1/1	–	2.2	*Malus baccata* (L.) Borkh. / Pine-birch-aspen forests with the participation of *Malus baccata* (L.) Borkh., *Acer negundo* L. – 2.2 ha
6.2	Borisovka forest district	–	1/1	–	0.6	Pine-aspen-maple forest in 1 compartment – 0.6 ha
7	Kuznetsovo Lake forestry					
7.1	Laptev Log forest district	–	3/2	–	2.9	Monodominant maple forests with the participation of *Populus tremula* L. in 1 compartment.
7.2	Topolnoye forest district	–	2/2	–	5.5	Mixed poplar-maple and aspen-birch forests.
	Total	56/36	175/99	54.1	311.1	

tricts. *A. negundo* occupies the vastest areas in the Barnaul forestry, the area that is most closely located to the regional center of Barnaul and the most densely populated. Over the 10 years from 2010 to 2018, the area of the maple distribution increased from 54.1 ha to 87.9 ha. In 2018, it was registered in 73 strata of 50 compartments. During the observation period, monodominant maple forests appeared on the area of 5.8 hectares. Along with the ash-leaved maple, other adventitious species that changed the species composition of the pine forest and tend to further spread were registered: *Fraxinus pennsylvanica* Marshall, *Malus baccata* (L.) Borkh., *Tilia cordata* Mill., *Salix fragilis* L., *Ulmus laevis* Pall.

There are great areas of forests transformed due to the participation of the maple in the Zimino forestry district – 31.4 hectares, with monodominant maple forests accounting for 8.8 hectares. This forest territory is adjacent to the settlement of Pavlovsk village.

In the part of the forest located at a distance from the cities but characterized by active forestry activities (the Novichikha forestry district), the area occupied by the maple is significant and accounts for 74.4 hectares. Monodominant maple forests are found in 5 strata and make up 17.9 hectares, while mixed willow-maple and maple-birch forests with the participation of the pine, willow and birch are registered in 13 strata. In the Krestyanka forestry district, the area of forests occupied by the maple is also rather vast and totals 39.1 hectares. In addition, there are also monodominant maple and mixed pine-maple forests in 3 strata (9.6 ha). The ash-leaved maple also appears in the part of the forest which is characterized by active recreational activity. In Kurortnoye forestry district, their area is 29.6 hectares. Approximately 40% of this area accounts for monodominant maple forests and maple forests with the participation of the pine, 60% is occupied by maple-pine and maple-pine-birch forests.

A. negundo plays the least important role in the formation of the forest communities in the extreme southwestern part of the Barnaul ribbon pine forest, which is distinguished by the most xerophytic environment and surrounded by arid steppe communities. The amount of precipitation here does not exceed 310 mm in the open steppe, with the annual evaporation rate of 230 mm, more than 50% of which evaporates in May, June (maximum evaporation), July. Therefore, in the Rakity and Kuznetsovskoe Lake forestries, the forest areas with the maple participation are scarce and amount to 2.8 and 9.4 hectares, respectively. However, even on this territory, in the Laptev Log forestry district of the Kuznetsovskoye Lake forestry, monodominant maple forests were found.

Over the ten-year observation period, the area of the maple and mixed forests with the *A. negundo* participation has increased almost 6 times in the Barnaul ribbon forest (from 54.1 hectares to 311.1 hectares).

Within the Barnaul forestry district, the coenotic structure of the *Acer negundo* coenopopulations was studied in the discount areas of 100 m^2. The ontogenetic state of the boxelder maple has two age periods – pre-generative one and generative one. We did not encounter senile individuals. Seedlings were extremely rare and were found only in those populations where crown density did not exceed 0.5.

The shooting generation required the soil free from herbaceous vegetation. The number of seedlings per 100 m^2 most often did not exceed 10–15. These plants had a monaxonic shoot and a non-branching main root. Several coenopopulations were characterized by the presence of juvenile plants that had a non-branching primary shoot, juvenile leaves, and a root system consisting of a primary root and a small number of lateral roots. The number of such plants on the examined plot could reach 25–30 specimens in the absence of grass cover. Coenopopulations with the predominance of immature and virginile plants were rather common.

Most often, the maple reached 2–2.5 m in height, sometimes it had the shape of a multitrunked tree with no more than 2–3 trunks (5–7 cm in diameter).

Not every coenopopulation was characterized by the presence of generative plants. On the whole, if the plants reached the generative state, males prevailed five-fold in the coenopopulation. Most of the studied coenopopulations consisted of pre-generative individuals, with the occasional young generative individuals. Most of the trees in the studied populations reached the age of 10–15.

Conclusion

Thus, the distribution of the maple in the flat part of the region is widespread: the species was not recorded in the highlands only. The shape of the maple tree depends on the habitat conditions in the Altai Krai and can vary greatly. The maple is actively settling throughout the Barnaul ribbon pine forest; however, it is characterized by different frequency and abundance in its different parts, having dissimilar natural conditions and the degree of anthropogenic transformation of the original communities. For the forest communities of the Barnaul forestry district, two age periods of the ontogenetic state were determined – pre-generative one and generative one. We did not encounter senile individuals.

Acknowledgements

The authors are grateful to Nadezhda Yuryevna Kurepina, candidate of geographical sciences (Institute of Water and Ecological Problems of the Siberian Branch of the Russian Academy of Sciences), for preparing the maps.

The study is carried out under the sponsorship of RFBR (Grant № 19-44-220006).

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